Amendments to Specifications

1. Page 1 (Abstract page), delete the paragraph regarding related patents and patent applications right above the Abstract.

2. Page 1, before "BACKGROUND OF THE INVENTION" add the following section title and paragraph:

RELATED PATENTS AND APPLICATIONS

This invention is related to U.S. Patent No. 5,754,147 issued 5/19/98, No. 5,954,414 issued 9/21/99, U.S. patent application Sr. No. 09/218, 938 filed 12/22/98, and U.S. patent application Sr. No. 09/253,656 filed 2/20/99.

3. Page 3, replace the paragraph beginning with "Alternatively, ..." with:

Alternatively, color images can be displayed by a combination of projections from several LCDs, each illuminated by a different color. For example, three LCDs, each illuminated by a light beam of red, green and blue color, can produce images of various color combinations by projection. For LCDs with high ~~response time~~ frame rate, such as display devices based on ferroelectric liquid crystals (called FLCD), a field sequential technique can be used to create color images using only one display device with no color triads [Displaytech].

4. Page 3, replace the paragraph beginning with "In addition to ..." with:

In addition to LCDs, there are other devices that are capable of only binary images or gray scales images. For example, digital micro-mirror device (DMD) consists a matrix of actuated small reflectors. By striking the matrix with a light beam and switching the position of each reflector, arbitrary images can be generated on the device and ~~canbe~~ can be projected [Thompson & Demond]. For another example, thin-film micro-mirror array (TMA) also consists of a matrix of piezo-actuated micro-mirrors and each mirror can be actuated at multiple positions to create gray scale [Kim & Huang]. And there are also many other micro-mirror based devices.

5. Page 3, replace the last paragraph with:

When used as the image source for volumetric 3D displays or for high speed optical correlators, the display device must have high frame rate. For volumetric 3D display, higher frame rate gives higher number of frames per image volume, hence higher resolution in the direction of screen sweep. For optical correlators, higher frame rate give higher processing (correlation) throughput. In these applications, display devices of binary image capability can give only limited color/gray capacity using conventional color forming practices. Particularly, field sequential technique is not suitable because each single frame has to have color/gray. Three display devices (R, G and B each) can be used to provide colors, but more display devices means higher cost. Color triad techniques can be applied, but fabricating color filter mosaic over display devices is costly, especially many high frame rate devices, such as FLCD and DMD, are reflective-type display and have fine pixels with pitch on the order ~~or~~ of 10 micro-meters. The previously mentioned spatio-chromatic illumination techniques are also difficult to apply to these reflective type displays. The gratings and micro-lens (or equivalent holographic optical elements) used to create color patterns are generally attached or placed close to the back of a transmissive type LCD. Building the diffractive optics on the reflective SLM or attaching them to the SLMs are not very desirable.

6. Page 4, replace the last paragraph with:

In general, the Pattern Projection technique illuminates an SLM with a light pattern comprising a 2D distribution of different values of a physical property of light. On the ~~display array~~ SLM, multiple pixels (or called sub-pixels) are grouped to represent one composite image pixel. The illumination of the light pattern over the ~~display array~~ SLM is arranged such that each sub-pixel of one image pixel is illuminated with a different value of the selected physical property of light, such as light intensity. By switching on or off selected sub-pixels ~~on one display panel~~, images with gray levels, for example, composed of selected sub-pixels of different light intensities, can be displayed. The illumination light pattern can be generated away from the SLM and then projected onto it. When the SLM is used as the image source in a projector, the illumination pattern also needs to serve as the light source of the projector. Illumination pattern can also be generated by using a proximity pattern plate close to the active surface of the SLM.

7. Page 5, replace the 2nd paragraph beginning with "Sub-panels ..." with:

~~Sub-panels~~ Images on different sub-panels on an SLM can also be separated in time domain into sub-frames to increase the effective frame rate of an SLM, by using a time-distributed illumination system to separate sub-panels carrying different light properties.

8. Page 5, replace the 3rd paragraph with:

Illumination intensity over different sub-panels on an SLM can be scaled to proper ratio so that the composite image on the SLM can present more intensity levels (or gray levels) than non-scaled illumination. The scaled illumination can also be applied among adjacent pixels and sub-pixels on the SLM in a structural pattern to achieve similar results.

9. Page 5, replace the 4th paragraph with:

Multiple sub-panels on an SLM can be merged optically into a single sub-panel. This helps to eliminate image artifacts associated with displays with color triads.

10. Page 5, in BRIEF DESCRIPTION OF THE DRAWINS, replace the paragraph of Fig. 3f with:

Fig. 3f shows the principle of separating images on different sub-panels in the time domain.

11. Page 6, replace the last complete paragraph beginning with "From the view ..." with:

From the view point of pixels, the Pattern Projection technique creates composite image pixels with color or gray levels by grouping multiple pixels (or called sub-pixels) to represent one composite pixel and illuminating each sub-pixel with a different color or intensity. By switching on or off selected sub-pixels on one SLM panel, images with color levels, composed of selected sub-pixels of different colors and intensities, can be displayed.

12. Page 8, replace the last paragraph with:

The multiple sub-panels on an SLM panel can also be separated into "sub-frames" to increase the effective frame rate. For volumetric 3D displays based on whole frame projection,

increased effective frame rate means an increase of image resolution in the direction of screen motion. This can be achieved by illuminating each sub-panel at a different timing and for a time period shorter than the frame period of the original display device. For example, in the case of Fig. 3a, a polarization rotator 350 can be added. A polarization rotator takes a linearly polarized light and can switch the state of polarization by 90 or 0 degree, depending on an input voltage signal. That is, a p-polarized light can be rotated to become s-polarized and vise versa. The device can also be set to "no rotation". Then the state of polarization is kept invariant. Switching the polarization rotator effectively selects path 301B+301M (both p-polarized) or 301G+301Y (both s-polarized) to pass polarization beamsplitter 140 and reach the SLM. In other words, it selects sub-panels 100B and 100M (M+B) or 100G and 100Y (G+Y) to be illuminated. By changing the status of the polarization rotator in the mid of each frame <u>period,</u> the images on sub-panels B+M and G+Y can be projected in sequence within the time period of one original frame, each for 1/2 the original frame duration, as illustrated in Fig. 3f. Fig. 3g illustrates how the two projected sub-frames look like. Sub-frame B+M contains images from sub-panels 100B and 100M. Sub-frame G+Y contains images from sub-panels 100G and 100Y. The effective frame rate is doubled, since each one full original frame is separated into two sub-frames.

13. Page 9, replace the paragraph beginning with "For applications ..." with:

For applications in volumetric 3D display, this sub-frame method is essentially a way of re-distributing pixels into the direction <u>of</u> screen motion to increase effective frame number in that direction. Accordingly, the total number of pixels in each sub-frame has to be reduced, to half of the original number in the case of Fig. 3g. However, it should be noted that the checkerboard-like pixel arrangement on each sub-frame as shown in Fig. 3g, although containing only half of the full-frame pixel number, still has the same position resolution as a full-frame, with a position error of one pixel.

14. Page 11, replace the last paragraph with:

By methods described in previous paragraphs, the projected color images still contains the "look" of color triad structure, because each sub-panel on the ~~display panel~~ <u>SLM</u> are physically separated by one or a few pixel pitches. This can result in undesirable artifacts in

color images. Applying a projection and path-combination optical system, similar to the one that projects the light pattern onto the display panel, can merge the physically separated sub-panels and put R, G and B sub-pixels into one single pixel, that is, eliminating the look of color triads. The basic concept is illustrated in Fig. 7a. Since the path separation optics and combination optics are similar, only one set of separation/combination optical system 780 is needed if the ~~display panel~~ SLM is of reflective types. Lens 120 projects the light pattern 100, which is generated by illuminating a pattern plate 110, onto the SLM 130 and projection lens 160 projects the image from the SLM onto the screen (not shown). The path separation/combination optics separates the illumination beam into multiple paths 781 leading to the display panel and partitions the display panel into four sub-panels 700. The same optics re-combines the images reflected from the four sub-panels and merges them into one single panel with each pixel comprising the superposition of four pixels each coming from a different sub-panel 790. Fig. 7b illustrates one example of this method. The path separation optics used in Fig. 3a are used as both path separation and combination optics. Lens 120a and 120b projects the light pattern on the pattern plate 110 onto the SLM 130, in four separated paths defining four sub-panels. Lens 120b and 160 act as projection lens and projects the re-combined images at a distance 180. The lens combination can be based on condenser lens or based on Schlieren optics. If desired, more ~~then~~ than two components can be used in the lens combination and those components can be spread among the components of the separation/combination optics if necessary. A TIR prism 740 separates the illumination beam from the image beam. Fig. 7c illustrates another apparatus example using the path separation optics used in Fig. 3c. This setup uses two sets of 3 dichroic reflectors (331 and 332) to separate the light beam into R, G and B three paths. Each dichroic reflector reflects only a selected band of light (R, G or B) and passes the rest. Projection lens 120 projects the light pattern onto the ~~display panel~~ SLM. The two sets of 3 dichroic reflectors are arranged as illustrated so that every path has the same length. (This is preferred when regular projection lens is used. If Schlieren projection optics are applied such that projection beams are collimated beams, then 3 dichroic mirror will be enough.) By adjusting the angle of each dichroic reflector, the three paths can be slightly offset to define three sub-panels. The image beams reflected from the ~~display panel~~ SLM are re-combined and projected by projection lens 160. The three sub-panels are merged into one.

15. Page 12, replace the last paragraph with:

In the above description, the path/color separation and combination optics are placed between the SLM and the projection lens. This arrangement may require a large optical path length between the display panel and the projection lens. An alternative method is to place the separation optics 780A before the SLM (i.e. upstream in the light path) and use path/color merging optics 780B after the projection lens. Fig. 8a illustrates the general idea. In order to merge multiple sub-panels into one, each sub-panel must carry a different light property so that the merging optics can align the beam associated with each sub-panel independently. The merging of sub-panels can be based on their different colors (in the cases of making color projectors) or on their different polarization states (in the cases of projecting B&W or gray scale images).

16. Page 16, replace the paragraph beginning with "Usually, ..." with:

Usually, on a FLC SLM, an inverted image frame is displayed immediately after one positive (non-inverted) frame is displayed in order to balance the electric charge applied to the FLC cells. Correspondingly, the switchable polarization rotator must change states at each frame. Since the FLC has a finite response time, there is a short transition period when the SLM inverts its image. During this transition period, the image has poor contrast. As frame rate increases, the effect of this transition period can appear. Also, this method of charge balance reduces ~~affective~~ effective frame rate, since every two successive frames look the same after the polarization rotator. Instead of the above "frame-by-frame" balance, a preferred method to balance charge is "stack-by-stack" balance, which displays a number of all-positive frames successively and then displays their inverted frames successively. The switchable polarization rotator changes states from stack to stack. This display method improves contrast at high frame rate.

17. Page 16, replace the last paragraph with:

Fig. 12b illustrates still another preferred embodiment of gray scale projector. The display panel is the type based on polarization, such as a FLC SLM. The setup is basically similar to that of Fig. 12a, except for a few additional components. Polarization difference is used for separation of illumination paths and for merging of the two sub-panels. However,

because the display image is also based on difference of polarization, some special treatments with use of additional components are needed. First, the images on the two sub-panels are defined to always have different polarization states. That is, when sub-panel 130A displays images of P state and background of S state, then sub-panel 130B displays images of S state and background of P state. In this way, the images from the two sub-panels can be separated by the polarizing beamsplitter 1221 into two paths and then merged together at a distance 180. A 1/2-wave plate 1265 is therefore needed to turn the polarization axis of one of the two images 90 degree, so that both images are projected with the same polarization state. A screen aperture 1212 is also needed to block unwanted half images from reaching the screen. Again, the polarization rotator 1270 ~~and~~ is used for projecting inverted image frames.

18. Page 19, replace the paragraph with:

When a shadow mask is used to create the light pattern, especially when the shadow mask contains micro-reflective patterns, a major problem is the need to recycle the light rays that are masked out to increase light efficiency. There are many ways to recycle the masked light. Fig. 16a shows one example for recycling converging light rays from a lamp with elliptical reflector 2. Placing the shadow mask (positive) 1610 at the focal point F2 can recycle a significant amount of reflected rays. Fig. 16b shows another example for recycling diverging light rays from a lamp with elliptical reflector. A spherical mirror R1 is used to collect rays reflected from the shadow mask. C2 is the mirror image of F2 as imaged by the reflector of the shadow mask. The center of curvature of R1 is placed close to C2, so that all rays reflected by the shadow mask are collected and returned to the shadow mask. A center hole on R1 is needed to allow the rays from the lamp to reach F2. Fig. 16c shows an example for recycling diverging light rays from a lamp with no built-in reflector. A spherical reflector R2 is therefore necessary to collect and return rays from the lamp at C1. A spherical mirror R1 is again used to collect rays reflected from the shadow mask. C2 is the mirror image of ~~C2~~ <u>C1</u> as imaged by the reflector of the shadow mask and the center of curvature of R1 is placed close to C2. Fig. 16d shows an example for recycling parallel light rays, when a positive shadow mask is used. The basic concept is using prisms or reflectors to recycle light rays. As illustrated in Fig. 15d-side, input rays 1601 are slightly inclined so that rays reflected by the shadow mask can enter prism B. Prism B is also inclined w.r.t. the shadow mask so that its reflective coating on one face 1625

can send rays back to the shadow mask. The inclination angles can be selected such that the rays reflected at the shadow mask can be sent back to the shadow mask with a desired position deviation of d1, e.g. N * 1/2 pitch of the spot pattern on the shadow mask, thereby the rays can pass the mask. Fig. 16d-top is the top view of the figure on the left. Prism B is slightly rotated to give a reflected deviation d2 in the horizontal direction, for similar reasons as d1. Fig. 16e shows another example for recycling parallel light rays, when a negative shadow mask is used. In this setup, a set of right angle prisms is used. Fig 16e-side shows the side view. Prism A has a size slightly different from that of prism B so that the recycled ray can be brought to a different location on the shadow mask. The shadow mask is slightly tilted w.r.t. the edges of the right angle prisms so that the reflected rays can leave prism B. Two mirrors can also replace prism A to achieve similar function. The size of prism A can be selected such that the recycled rays can be brought back to the front of the mask with a desired position deviation of d1. A d1 value of N * 1/2 pitch of the spot pattern on the mask can make the rays be reflected by the mask. Fig. 16e-top is the top view of the figure on the left. Prism A is slightly rotated to give a reflected deviation d2 in the horizontal direction, for similar reasons as d1. Fig. 16f <u>shows optics</u> ~~Optics~~ for recycling parallel light rays from a lamp with a parabolic reflector. The basic concept is using the parabolic reflector to recycle the light rays directly. Fig. 16g shows another example for recycling parallel light rays from a lamp with a parabolic reflector. It uses an integrator 1607 with two lens 1608 can make the parallel beam reaching the shadow mask more uniform. The spherical mirror R1, centered at F1, recycles rays being reflected back to the parabolic lamp reflector around the optical axis (center region). More discussions and methods of lamp light rays recycling methods can be found in [Rosenbluth and R.N. Singh].

19. Page 21, replace the 2nd paragraph with:

The techniques described above can also be applied to a display system using more than one SLMs. In such cases, images from each SLM can be merged and displayed. For example, using a dichroic color cube, a white light <u>illumination pattern</u> can be separated into RGB three primary colors each illuminating one SLM, and images from the three SLMs can also be merged. For another example, an optical setup similar to that of Fig. 10a can also be used, with 130R-130B each representing an SLM. With multiple SLMs, sub-panels from different SLMs can be optically overlapped and displayed when desired.